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# Inspection of the TRIGA Reactor Tank

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## ABSTRACT

Nuclear components are under strict supervision of operators and safety authorities. The Reactor Centre of the Jožef Stefan Institute decided to make an inspection of its TRIGA Mark II research reactor to verify the conditions for long-term future operation within the on-going periodic safety review. Two main inspection methods were used: ultrasonic and visual inspection. Ultrasonic inspection was selected to prove that there is no significant reduction of wall thickness anywhere in the tank. The inspection confirmed that the reactor tank has not been degraded or corroded. In the future such inspection will take place every 10 years within the periodic safety review in order to monitor every 10 years the reactor tanks condition.

## 1 INTRODUCTION

Almost every piece of industrial equipment has a projected life-time from the very beginning of its operation. The life-time is normally defined on the basis of operational experience and is always determined in a conservative manner. On one hand, poor maintenance shortens the life-time and on the other hand, good maintenance and good operation can prolong the predicted period of individual component operability. Very important facts are also received from new research results in the field of aging of different materials.

Nuclear components are under strict supervision of operators and safety authorities. The Reactor Centre of the Jožef Stefan Institute (JSI) decided to make an inspection of its TRIGA Mark II research reactor to verify the conditions for long-term future operation within the on-going periodic safety review (PSR). Main information for PSR comes from the in-service inspection. In-service inspection contains a program of examinations, testing, and inspections to prove adequate safety and to manage deterioration and aging effects [1].

The inspection of the reactor tank was planned to be performed within the PSR from the beginning as the reactor tank is critical for normal and safe operation of the reactor. In addition it is the structure that is the most difficult to replace. The tank is made of aluminium and holds de-mineralized water under normal pressure at temperatures below 37 °C. It was not expected to be significantly degraded or corroded. In order to verify this assumption, the operator decided to perform detailed inspection of the reactor tank wall. Q Techna d.o.o. was selected to perform the task; mainly due to professional references on other similar nuclear installations (e.g. inspection of the nuclear power plant (NPP) Krško spent fuel pool).

Two main inspection methods were used: ultrasonic and visual inspection. Ultrasonic inspection was selected to prove that there is no significant reduction of wall thickness anywhere in the tank. Detailed visual inspection confirmed that there are no visually detectable defects like cracks or any other unacceptable surface defects. The main challenge of the inspection was that it had to be done under water from the inner side of the tank and, especially at the bottom of the tank, very close to a strong source of radiation, as the core was not removed during inspection. The challenge was met by selection and professional use of appropriate equipment and techniques.

Procedures, approach and the main findings are presented in this paper.

## 2 PERIODIC SAFETY REVIEW

The purpose of the PSR is to systematically review ageing effects, effects of various changes in the facility, operating experience, new developments in the field, changes in characteristics of the reactor site and all other possible effects on nuclear and radiation safety. In addition it should be proved that the reactor facility is still compliant with the newest safety standards, legislation and international recommendations. All this is needed to confirm that the reactor is at least as safe as at the beginning of operation and that it is capable of future safe operation.

The PSR programme of the JSI TRIGA reactor was prepared in compliance with the valid Slovenian legislation [2], practical guidelines prepared by the Slovenian Nuclear Safety Authority (SNSA) [3] and with the IAEA guidelines for the review of the research reactor safety [4]. In addition we used IAEA safety standards [5], [6] and [7]. The programme was approved by the SNSA in November 2011. The reference date was determined to be January 1$^{st}$ 2011. The estimated duration of the PSR was three years and the financial costs were estimated to 700,000 €. The most important task within the PSR was the inspection of the reactor tank, as it had never been inspected before. In addition this component is critical as it is the one which cannot be replaced easily.

## 3 CONSTRUCTION OF TRIGA REACTOR

### 3.1 General

The TRIGA Mark II research reactor at the JSI in Ljubljana, Slovenia was built in 1962-1966 and achieved first criticality on 31$^{st}$ of May 1966. It is a pool-type light water reactor with a annular graphite reflector and cooling by natural convection. The side view of the reactor is shown in Figure 1.

It is of essential importance to know and understand the construction of the TRIGA reactor when performing a PSR. This is the basis for evaluation of possible problems that could occur during the operation.  The reactor is an open cylindrical vessel with a flat bottom end. It is 4870 mm high and 1982 mm in diameter. It is made from aluminum alloy 5052 H34. The minimum thickness of the vessel is 6.35mm. It was welded with fusion welding. All welds were inspected with radiographic examination (RT), with liquid penetrates and with bubble tests. The vessel as a whole was tested with a pressure test. The reactor is not stamped but it fulfils applicable portions of ASME Boiler & Pressure Vessel Code Section VIII requirements. The reactor tank during the construction is shown in Figure 2.

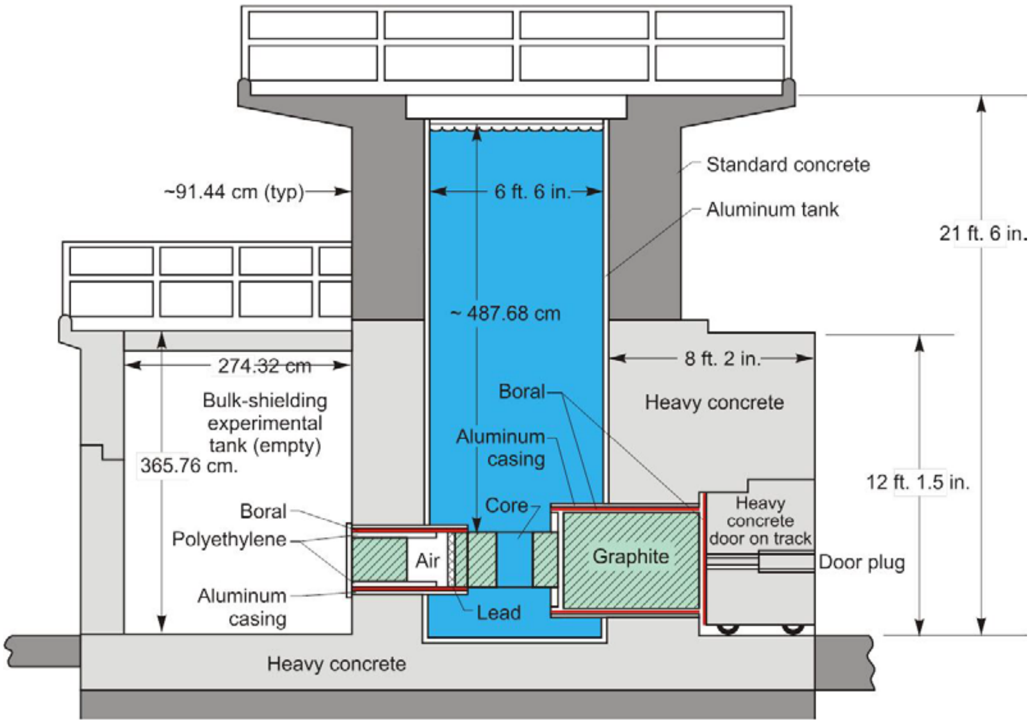


Figure 1: Side view of TRIGA Mark II reactor

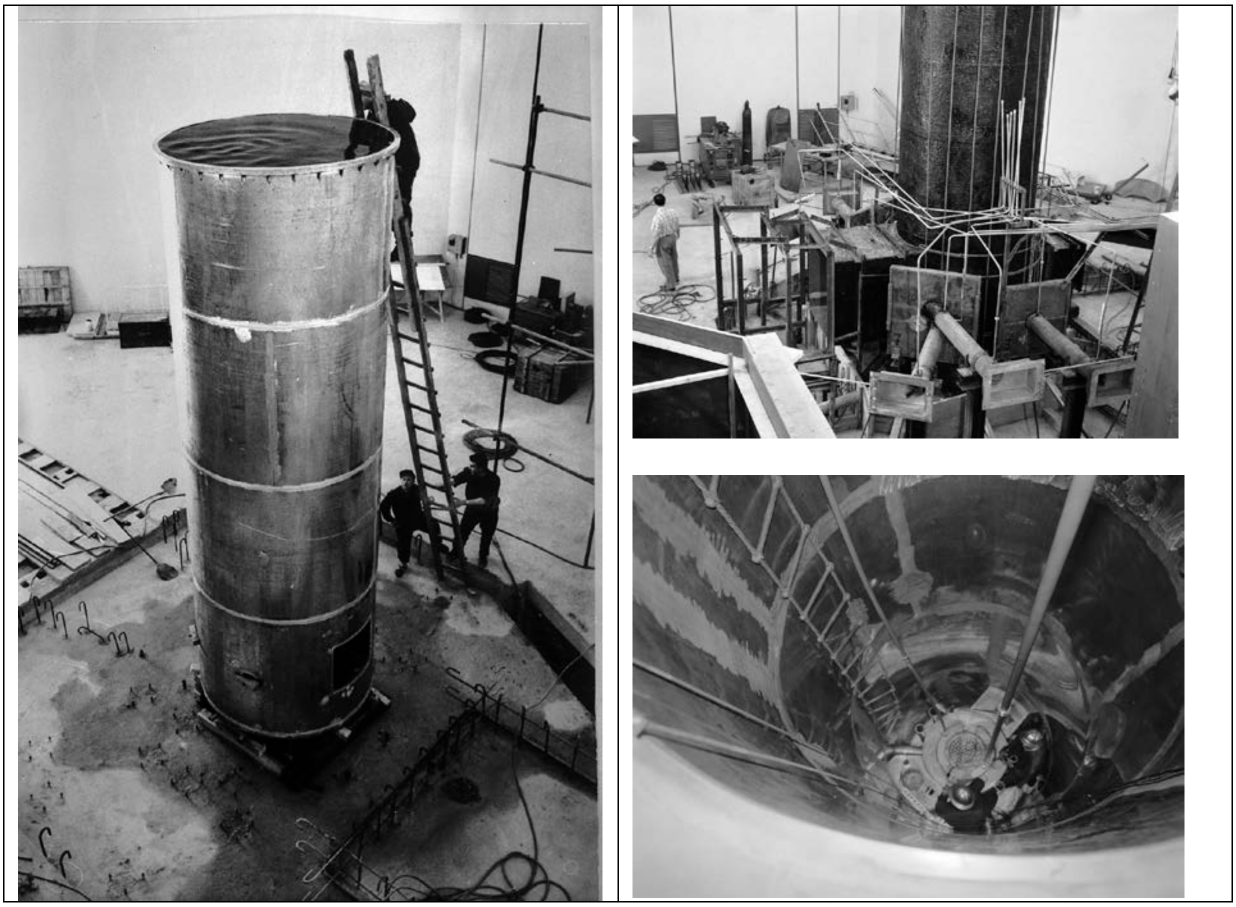

Figure 2: Photos of the TRIGA reactor tank during the construction

The reactor tank is externally protected with two layers of bituminous #15 saturated felt wrapped around it. The tank is placed in the heavy concrete, and it is not accessible from the outer side.

The weight of the empty tank is 1080 kg and the weight of the reactor vessel filled with water is 18,780 kg. It was by designed by General Atomics and manufactured by Slovenian company Hidromontaža.

### 3.2 Analyses of possible degradation processes

Demineralized water has been used as the reactor coolant and for radiation protection since the very beginning. Aluminum alloys are resistant to this fluid and from a design point of view corrosion was not expected. But during the operation unexpected situation could occur like: an unintended change in water chemistry or contact with some other metals like stainless steel. These could provoke galvanic corrosion which is many times connected with submerged and embedded structures. In the case of the TRIGA reactor we have both situations. Since the structure is visible from the inner side larger degradation processes could be seen from the platform. Much more problematic is the embedded side. Galvanic corrosion is a local corrosion and could occur on a very small area that is not accessible or it is hidden. A typical area is the bottom of the reactor from the inner side, where a support construction for the reactor core is located.

Due to the non corrosive medium and properties of aluminum there is almost no possibility for general corrosion. But in the case that by accident some mercury comes in contact with the vessel, intergranular corrosion occurs. Mercury pollution of aluminum provokes severe irreversible degradation processes [8].

Special emphasis always has to be put on welds. Aluminum alloy 5052 H34, or with ISO designation AlMg2.5, contains 2.5% of magnesium as a principal alloying element. Such a material has good weldability. Since the welds were examined by RT during construction it is presumed that there are no unacceptable volumetric irregularities in the welds. But despite this aluminium is sensitive to lack of fusion which cannot always be detected with RT. Welds have different structure as a base material; residual stresses, irregularities and discontinuities etc., are present. For that reason degradation processes like cracks could occur in welds or in the heat affected zone.

### 3.3 Inspection methods

On the basis of analyses of possible degradation processes an inspection plan and scope of inspection was defined. It was foreseen that two main methods would be used:

- Visual inspection
- Ultrasonic inspection

Detailed visual inspection of all inner surfaces was performed. This included base materials, welds, bolting materials and surfaces of other internal components. The main purpose of this inspection was to detect possible degradation processes like corrosion, cracks and mechanical deformations.

Ultrasonic inspection gives information about processes from the outer side. If the wall thickness is not different from at the time of construction, this indicates well, that there are no corrosion processes from the outside. It is of essential importance that scanning is detailed enough, i.e. measuring points are not more than 500 mm apart.

Q Techna has much experience in in-service inspection on commercial NPP`s locally and abroad, but this was its first activity on a nuclear research reactor. Approach for inspection was the same as in NPP`s, meaning that all prerequisites had to be fulfilled especially from the points of nuclear safety and quality.

## 4 VISUAL INSPECTION

### 4.1 General

Visual inspection is the basic method to detect discontinuities, defects, degradation and similar undesired conditions or processes. It reveals a great deal of very important information and in many cases it is essential information for interpretation of results obtained by other methods. Of course it is desired to have a possibility for direct visual inspection, but in many cases that is not possible. Especially in the nuclear field remote visual inspection is used very often. The main obstacles for direct visual inspection are accessibility and radiation.

Visual inspection is very often underestimated, but it requires much theoretical knowledge, practical training with different materials and defects and a capability to use different equipment. It is essential to have skills to interpret images in a proper way.

### 4.2 Execution of visual inspection

In the case of the TRIGA reactor it was obvious that only remote visual inspection could be applicable. The reactor is filled with water continuously. For this reason it was decided to use a special underwater camera that could be used also very close to sources of radiation like fuel elements. For such an application charge coupled device (CCD) cameras could not be used.

Camera Mirion Technologies IST-REES R90 MK 3 CCU was used. It has built in an additional source of illumination. It is connected to the control unit with a cable. To operate the camera guiding tubes as a manipulator were prepared. The system was verified in laboratory with a performance demonstration.

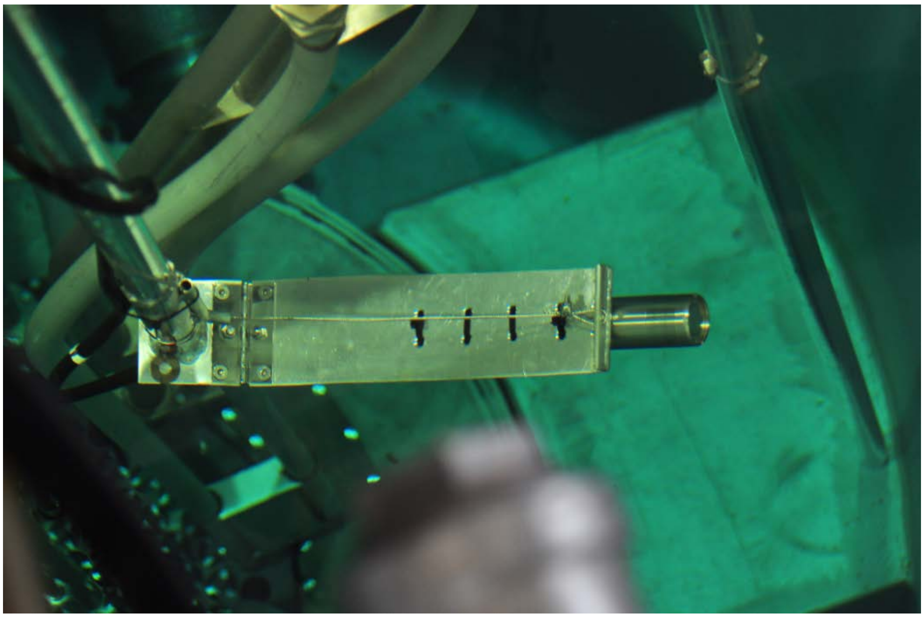

Figure 3: Camera for visual inspection

Before inspection began the whole system (camera-monitor-recorder-text generator) was properly calibrated on-site. The system was calibrated with a calibration chart (line with thickness of 0.8mm) recorded at a distance of 150mm, 500 mm and 1000 mm. The calibration procedure was documented and enclosed in the final report [9].

The camera did not have a fixed connection to the guiding tube. Connection permitted rotation of the camera in a vertical direction allowing for examination of surfaces from different angles. An operator was moved the tubes to position the camera and moved the camera`s angle with metallic rope. A picture of camera fixation is in Figure 3.

Inspection requires at a minimum three persons present on site. Two were responsible to manipulate the camera and one to interpret and evaluate. It was also essential that the coordinator was present at all times. As the reactor is used mainly for research and education, the reactor tank is full of various tubes, channels, fuel racks and other components that make the manipulation of the camera more demanding. For this reason the coordination of the camera path was needed.

Figure 4: Work on the platform during visual inspection

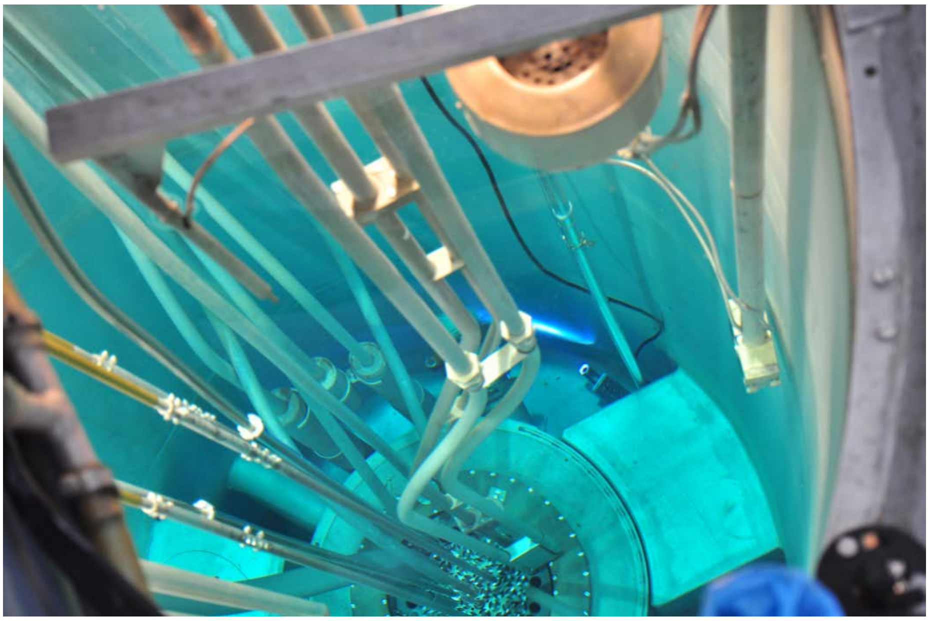

Figure 5: Bottom of TRIGA reactors with different internals

The scanning path was planned in the advance. Inspection was done at levels all around the tank. The camera does not permit a very far view and for this reason much scanning was needed. The upper part is not so complicated relatively for inspection because there are not so many components and structures. At the bottom of the tank the situation is completely different. There are guide tubes, irradiation channels, nuclear instrumentation, fuel element storage racks, the reactor core, thermalising column, thermal column, pipes (thruports), etc. It can be seen in Figure 5 that the configuration at the bottom of the vessel is quite complicated for visual inspection.

There was a requirement that at a minimum 95% of all vessel surfaces were to be examined, which was fulfilled. Furthermore due to the construction of the manipulator 99% of the surface was inspected.

During the inspection no degradation processes like cracks or major corrosion areas were observed. There were also no other indications like mechanical damage due to the fall of heavy loads or collision with a sharp hard object. On the bottom of vessel some small foreign material and small local corroded areas were observed. It is assumed that corrosion areas appeared from foreign material which had been removed from vessel in the past.

All sections and positions were marked on recordings. This permits traceability for this inspection and also a possibility to compare recordings with new ones recorded in the future.

## 5 ULTRASONIC INSPECTION

### 5.1 General

Ultrasonic inspection was an additional method for visual inspection. In the case of any degradation processes it would be necessary to further investigate those areas.

In our case that was not necessary. The plan of inspection was prepared in advance. It was foreseen to measure the thickness of the vessel along eight verticals 45° apart. Measuring points were along a vertical line 300 to 500 mm apart. At least 20 measurements on each line on the bottom were performed.

### 5.2 Execution of ultrasonic inspection

Ultrasonic inspection was performed under water and required a specific approach. The underwater technique requires some different preconditions from inspection outside water. The procedure was basically prepared as an immersion ultrasonic technique. First of all the ultrasonic probe as well as cable connections must be water tight. The ultrasonic probe must be at a distance from the metal sheet and this distance must be maintained precisely during the entire measurement. Employment of water is as a contact mean and as a delay line that one element transducer can be used for thickness measuring. A very similar guiding tube was used for visual inspection. In addition this guide had a scale which showed vertical position. The ultrasonic probe was fixed to the guiding tube with a tilting connection. For the vertical part the probe was in one position; along the bottom the probe was turned in another position and another was selected along the transition radius between the vertical and bottom horizontal part. The ultrasonic probe and system of guidance can be seen in Figure 6.

For measuring the following equipment was used: ultrasonic equipment Krautkramer USN 58L and a probe K5K with 5mm vibrator in diameter and a nominal frequency 5MHz.

In laboratory's performance demonstration was conducted with identical material that was used for construction of the vessel. Calibration was performed in equivalent conditions to those on site. The basic parameter for calibration and later thickness measurements taken on-site was the measuring distance from the water/metal interface echo to the first back wall echo using the ultrasonic system. In addition the repeatability of measurements was confirmed.

The measuring system was again calibrated on-site. Calibration was done with a step calibration block.

All personnel were appropriately trained in the same approach applied for visual inspection. Training was performed on a mock-up in laboratory.

Inspection on-site was done from the platform. Scanning was done along the same vertical lines as for visual inspection i.e. eight lines. Due to the geometry in the transition between the wall and bottom of the vessel it was not possible to maintain a constant distance to the water column. For this reason measurement was done between the first and second echo from the back wall.

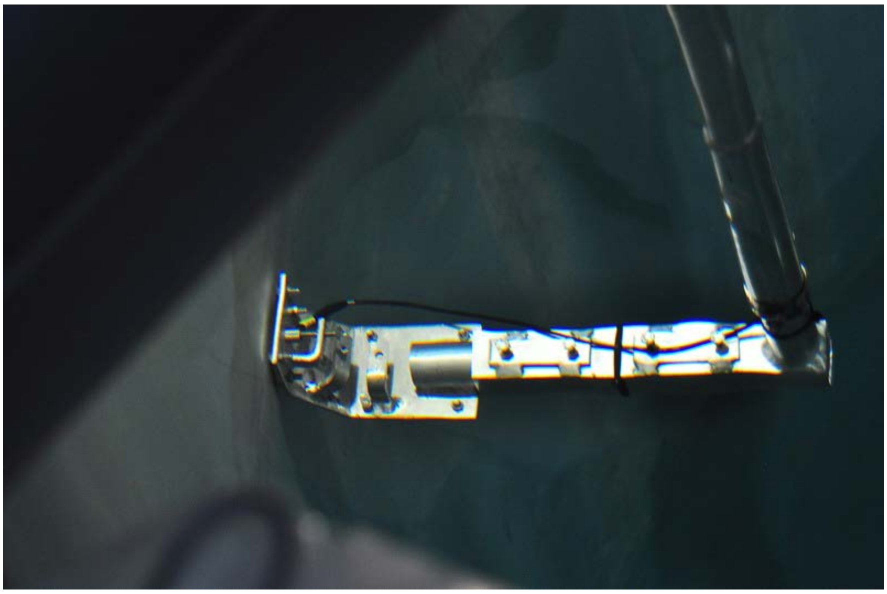

Figure 6: Ultrasonic probe

Locations where thickness was measured were positioned as a grid on the cylindrical and bottom parts. Thirteen measuring point were made in the longitudinal direction of cylindrical part 300 to 500mm apart, and eight divisions were made in the circumferential direction. The bottom was divided at four locations in the radial direction and the cylindrical part in eight divisions in circumference direction. Positions of measuring points were dependent sometimes on obstruction configuration in the vessel. Wall thicknesses of the cylindrical part were between 5.6 and 6.7mm and on the bottom 5.8 and 6.5mm, and no essential deviation from the nominal thickness was detected. Also in between the measuring points the thickness was scanned to discover any changes.

## 6 CONCLUSION

An appropriate method for visual and ultrasonic testing of the JSI TRIGA Mark II reactor vessel was successfully developed and applied.

Visually the vessel is in good condition, and there were also no indications that wall thickness has diminished.

All inspections performed show that there are no significant degradation processes taking place in the reactor tank.

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